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DEVELOPMENT OF A NEW INFANTRY HELMET (U)

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The subject of military helmets is an ancient one. A helmet not only provides protection for the head but also serves as an identification symbol for entire armies. The identification symbol for the US Army is the M-1 helmet system. The M-1 steel shell and plastic reinforced cotton liner was adopted by the Army in June 1941. An improved ballistic liner (nylon) was type classified in March 1961 and a more comfortable chinstrap was adopted in 1972. However, all efforts by the Government and Industry to product improve the suspension system to counter the numerous complaints from the field proved fruitless. The complaints from the field focused on the areas of stability, fit and comfort.

Analyzing these areas, one can conclude why product improving the suspension system would offer only marginal relief to the soldier. The high center of gravity of the M-1 helmet system causes rotational forces which cannot be corrected by modification of the suspension system except by lowering the helmet on the head which of course would interfere with vision. These forces may ultimately be reported in a complaint of the helmet being unstable, too heavy or uncomfortable.

The fit problem is clear when one considers that the M-1 helmet system is issued in one universal size. At least 50% of the troops should complain of poor fit. The rotational forces of the helmet onto the head are accentuated on the smaller half of the Army population. Comfort, too, may be linked to the instability of the helmet and may be manifested in complaints of the helmet being too heavy, causing headaches or irritating the head.

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An additional problem that sometimes exists with the M-1 system is the misfit of the nylon liner inside the steel shell. This misfit can be caused by a slight distortion of the nylon liner. The net result is that the steel shell rides slightly high on the nylon liner and has a tendency to wobble or separate from the liner when the soldier runs with his chinstrap unfastened. This problem also magnifies the complaints of the helmet being too heavy, not fitting, and uncomfortable.

A need therefore exists for a new infantry helmet that will provide improved fit, comfort and stability over the standard M-1 system.

2. NEW HELMET PROGRAM

a. Objectives and Organization

The US Army Natick Research and Development Command (NARADCOM) solicited and involved the expertise of the Army Materiel Development and Readiness Command (DARCOM), formerly AMC, in the preparation of a program for developing a new infantry helmet. The program was to emphasize ballistic protection and troop acceptability.

Two approaches were to be taken with regard to ballistic protection:

1. Develop a helmet with increased ballistic protection at the same weight as the M-1 system.
2. Develop a helmet with equal M-1 ballistic protection at less weight than the M-1 system.

Using either approach the helmet should be designed to make the most efficient use of the ballistic material. Therefore, the helmet should be designed to come as close to the head as possible consistent with the physical limitations and mission of the soldier.

This became the underlying philosophy of the helmet program. To further appreciate this philosophy, envision a head completely encapsulated by a form fitting helmet which represents maximum protection. Every design aspect reducing the ideal coverage such as cutouts for face, vision, hearing, etc. or any change in the helmet head standoff was to be fully documented by a corresponding study. This philosophy evolved into a helmet development program

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which was incorporated into the AMC Five Year Personnel Armor System Technical Plan. The Technical Plan was approved by the Department of the Army in April 1970.

The participating Agencies or Laboratories included the following: US Army Natick Research and Development Command (NARADCOM), Natick, MA; US Army Human Engineering Laboratory (HEL), Aberdeen, MD; US Army Ballistic Research Laboratory (BRL), Aberdeen, MD; US Army Materiel Systems Analysis Agency (AMSAA), Aberdeen, MD; US Army Edgewood Arsenal, Edgewood, MD; US Army Mechanics and Materials Research Center (AMMRC), Watertown, MA; US Army Research Institute for Environmental Medicine (ARIEM), Natick, MA; US Naval Research Laboratory (NRL), Washington, DC.

The work units of the initial plan and the inputs of the various laboratories or agencies are listed in Table I. Implementation of this plan necessitated the close cooperation of each of the participating Laboratories. Natick Research and Development Command managed and coordinated all work efforts as to content and timeliness.

This paper presents a description of the developmental phases of the new infantry helmet; the pertinent results of studies are cited but the detailed data are included in the program reports listed in the bibliography.

b. Background Studies

Two studies were initiated simultaneously to provide a uniform baseline for the entire program. The first study consisted of the historical documentation of the M-1 Helmet System(1). The second established the state-of-the-art on a world-wide basis of helmet designs, materials and suspension systems(2). The documentation study traced the M-1 from its conception to the present day and confirmed all the systems shortcomings as well as documented all modifications and attempts at improvements in the system. The state-of-the-art report consisted of a survey of foreign helmets from both friendly and unfriendly nations. From the final report one concludes that other countries have the same problems with their infantry helmet as the US Army. The complaints of foreign troops also center about the areas of stability, fit and comfort.

3. SIZING

To design a close fitting helmet from a rigid ballistic material one must first establish generalized shapes of heads for

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the Army population.

TABLE I
PROGRAM WORK UNITS

Work Unit No.	Input Laboratory
1. Mathematical Model of the Head	BRL, NARADCOM
2. Verification of Math. Model of the Head	NARADCOM
3. Configuration and Production of Research Prototypes	NARADCOM
4. Sizing Evaluation of Prototype Helmets	NARADCOM, HEL
5. Documentation of M-1 Helmet and Liner	HEL
6. Effect of Helmet Form on Hearing	HEL
7. Human Factors Engineering Support	HEL
8. Physiological Evaluation	ARIEM
9. Casualty Reduction Studies	NARADCOM, AMSAA
10. Casualty Criteria	BRL
11. Ballistic Testing	EA, NRL
12. Materials Program	AMMRC, NARADCOM
13. Tactical Doctrine Interface	NARADCOM, TRADOC
14. Threat Analysis	AMSAA
15. Systems Development Plan	NARADCOM
16. Reliability and Maintainability Criteria	NARADCOM
17. Suspension Studies	NARADCOM
18. Retrieval and Analysis of Design Data	NARADCOM
19. Fabricate Experimental Helmets	NARADCOM
20. Fabricate ET/ST Helmets	NARADCOM
21. Coordinated Test Plan	NARADCOM
22. Establishment of Utilization Doctrine	NARADCOM
23. Production Engineering Effort	NARADCOM
24. Establish Systems Specifications	NARADCOM
25. Establish Type B2 MIL-STD-490 Critical Item Developmental Spec.	NARADCOM
26. Establish System Technical Data Package	NARADCOM
27. Engineering and Service Testing	TECOM/AMSAA
28. Personnel and Training	NARADCOM
29. Annual Technical Review of Plan	Program Working Committee

A review of the available anthropometric data revealed that large data gaps existed as to the shapes of human heads. Considerable data exist for point to point measurements on the head such as length, breadth, height and circumference, but no information was available as to the relation of any particular measurement with

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that of another nor were there any intermediate points measured on any given head. In other words, spatial or three dimensional information was totally lacking from the data.

Under work unit #1 of the Helmet Program, the Ballistic Research Laboratories (BRL) were charged with the development of a mathematical model of the head, using the available anthropometric data existing in the 1966 Army Anthropometric Survey by White and Churchill (6600 subjects) and the 1961 Survey of Army Aviators by White (500 subjects). BRL successfully developed a series of algorithms(3,4) which related the four basic head dimensions of circumference, length, breadth and height and by which the Army population was capable of being sized. The sizing algorithm yields various size systems. Although this is the first time an effort was made to relate the four basic dimensions, information was still lacking pertaining to the intermediate points necessary for describing the shapes of heads.

Several avenues of approach were taken to fill in the missing data. Two unsuccessful approaches were the biostereophotometric method and the "Prince Charming" method. The former method used a series of five pairs of cameras and the resolution of points into an x, y, z coordinate system. Although this method looked promising for point to point body measurements, it offered no immediate solution for describing the surface of heads. The latter method involved measuring the heads of over 600 men at Fort Devens, MA and by computer, selecting the "Prince Charming" for each of the BRL size categories. The soldier who most nearly fit all the dimensions of each size category was selected and had his head cast molded, digitized and positive models made. It was hoped that the "Prince Charmings" would serve as umbrella heads for each size category. But such was not the case. The individual bumps and contours of the model heads seldom matched the contours of other heads within the same size category.

A third method that proved successful took advantage of the relatively few anthropometric landmarks on the head. The concept was to measure heads from a known geometrical surface in such a way that the landmarks of the heads were always referenced to certain points on the geometrical surface. The idea reduced to practice consisted of a 14 inch (35.6 cm) diameter clear plastic hemisphere having 27 movable probes on the surface. The spherical coordinates of each probe were known and each probe passed through the center of the sphere.

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The measuring process required restraining the subject's head in the Frankfort plane by means of a bite bar, then lowering the hemisphere over the head in such a way that the equatorial plane of the hemisphere was aligned with the subject's right tragus and right external cantus, with the diameter passing through the right tragus. The vertical diameter plane was aligned with the subject's mid-saggital plane. The center of the hemisphere thus fell approximately midway between the subject's tragi (see Fig. 1). All 27 probes were depressed until they contacted the subject's head and the lengths of the probes were measured. Thus, the spherical coordinates of the 27 points on the head became known as well as the lengths of the rays emanating from a point between the tragi to the surface of the subject's head.

Using two of these devices, called 3D Numerical Surface Descriptors, heads were measured at Fort Devens, MA in February 1973. In addition to the head surface measurements, the four basic dimensions were measured on each subject. The data on each test subject was sorted into the BRL nine-size system according to their basic head dimensions; they were then re-sorted into three selected sizes (of the nine-size system) which would yield an estimated tariff of 20%, 50% and 30% for small, medium, and large, respectively. The sizes selected from the nine-size system were 1, 6 and 9.

The statistics for the probe readings of each size were determined by computer. In essence, the computer generated a set of 27 probe readings which maintained the four basic dimensions for each size category. Thus, three distinct networks of points (ray terminal surfaces) were established by which each size category could be shaped.

The National Academy of Sciences-National Research Council, Committee on Helmets, who reviewed the program, describe this effort as the most comprehensive anthropometric data gathering program ever established for the head.

The computer probe data were given to an expert sculptor and consultant to the Natick Research and Development Command and he, using one of the 3D Numerical Surface Descriptors, fashioned three headforms representing the three-size categories (see Fig. 2). The probe data given to the sculptor and the corresponding head rays are recorded (6). The headform dimensions are also recorded in (6).

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Fig. 1. A 3D numerical surface descriptor.

Fig. 2. Plaster headforms in three sizes representing the US Army population.

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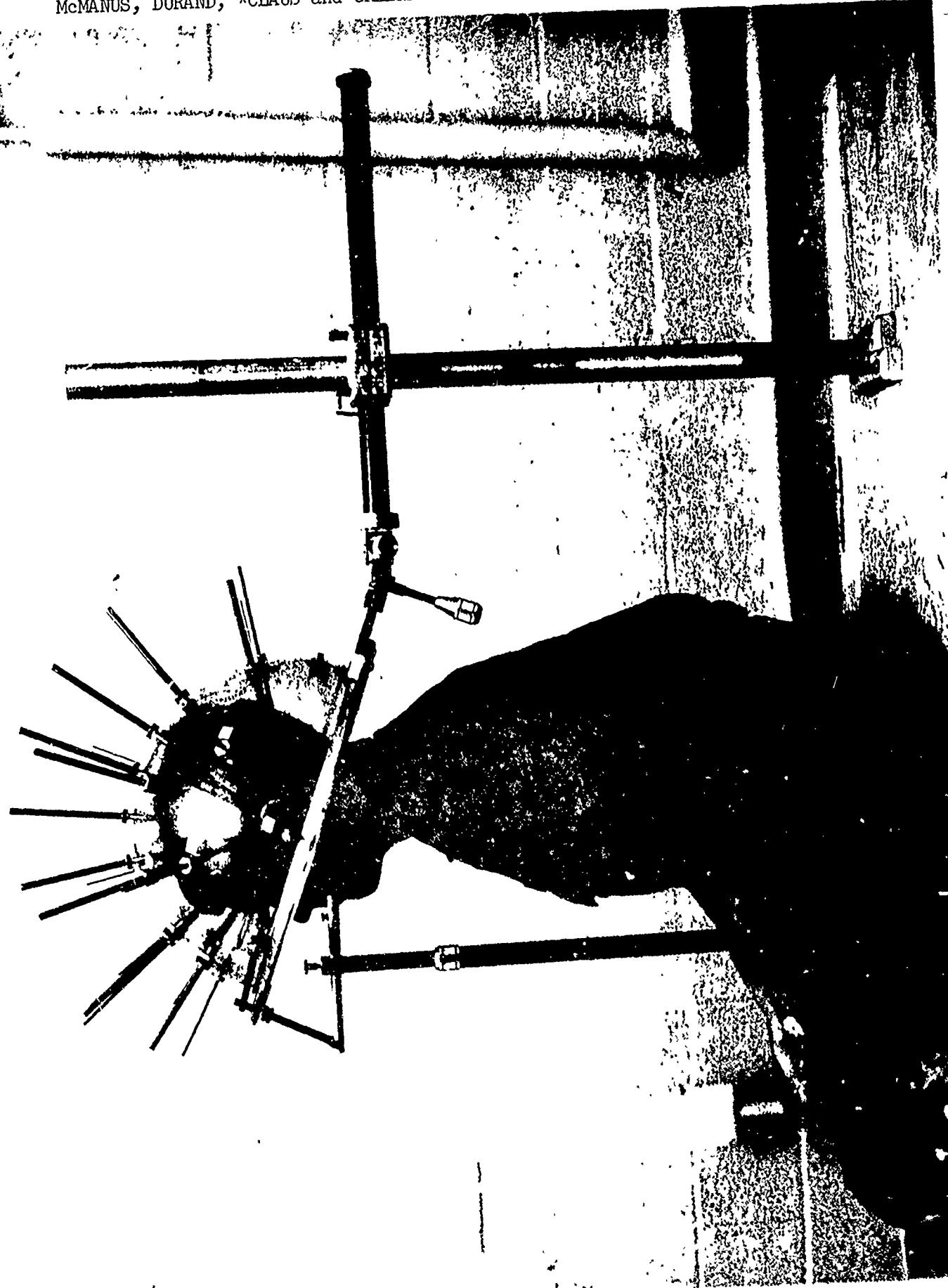


Figure 1

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Figure 2

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4. DETERMINATION OF STANDOFF DISTANCE

Simultaneous with the work on shapes and sizes of heads, other DARCOM Laboratories were conducting investigations to generate basic information pertinent to the design of the helmet. Studies included ventilation parameters, transient deformation, audio and visual envelopes, weapon and equipment compatibility as well as helmet weight perception and ballistic material evaluation. The transient deformation and heat transfer studies form the basis for selecting the proper standoff of the helmet from the head.

The Bio-Physical Laboratories at Edgewood Arsenal, Edgewood, MD conducted ballistic transient deformation evaluations on various helmet candidate materials(7,8). Transient deformation is defined as the maximum distance a given material will momentarily deflect when impacted by a missile of known mass fired at a non-penetrating velocity. This information was required in order to design the helmet with sufficient standoff from the head to protect against transient deformation impacts. The conclusion of these evaluations is that a one-half inch (1.3 cm) standoff is sufficient distance between the head and the helmet when using the most promising ballistic material (Kevlar).

The heat stress problem was addressed by the Army Research Institute of Environmental Medicine (ARIEM). A fully instrumented "copper man", used to measure the insulation values and the vapor transmission coefficients of clothing systems, was used on the helmet problem. Descriptions of the test equipment and the methods used to evaluate ensembles are contained in Fonseca's survey report(9) of headgear. The physical model, the copper manikin, is sectioned with independent thermal controls so that the head alone can be considered the test section for headgear studies.

Two important aspects of Fonseca's study are the effects of ventilation holes in helmets and the effects of increasing the percentage of the head covered by a helmet. By removing differing amounts of material (up to 8%) from a helmet to provide ventilation and then measuring the thermal properties of the modified helmets, Fonseca concluded that such holes did not increase the evaporative heat transfer from the head in a practically significant way. Also by systematically removing strips of material from an experimental shell (covering the temple, ear and neck areas), evaporative heat transfer was increased little until nearly 30% of the helmet was removed.

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Another design parameter systematically studied was the standoff required for optimum ventilation. Custom shells were vacuum formed from clear plastic with varying standoff distances and the insulation values were measured(9). The conclusions of these studies like the transient deformation study indicated that one-half inch (1.3 cm) standoff was adequate to provide optimum ventilation.

The determination of the standoff distance represented the first helmet design parameter. Helmet designers were now able to have "working helmet molds" made over which helmets could be designed. The sculptor was given a new set of probe readings for the "working helmet molds" which represented the headform probe readings symmetrized with one-half inch (1.3 cm) added to each reading. Symmetry was accomplished by selecting the larger reading of the paired left and right probes. The "working helmet molds" essentially represented the inside of future designed helmets.

5. EDGE-CUT CRITERIA AND HELMET DESIGN

An example of the close cooperation and management of this program was manifested by the coordination of the Human Engineering Laboratories' (HEL) work with Natick Research and Development Command's efforts. As the "working helmet molds" were being made by Natick, HEL was completing their work on vision, audition, weapon, clothing and equipment compatibilities and how they affect the edge-cut of a helmet. Although most of these studies are reported separately(10,11,12,13), the compounded effect is reported in a Summary of Infantry Helmet Edge-Cut Criteria dated November 1973(14).

Natick Research and Development Command, with the assistance of HEL personnel using the data in (14), literally inscribed the edge-cut criteria on the "working helmet molds". The molds then had a line of demarkation above which a helmet could be designed having maximum vision, audition, weapon, clothing and equipment compatibilities, and below which a helmet design would interfere with one or more of an infantryman's operation or mission.

An important factor in the helmet edge-cut criteria was that most of the ear and temple areas could be covered by the helmet. This extremely important point meant that helmets could be designed which could cover more of the head and this, coupled with the low one-half inch (1.3 cm) standoff, would lower the center of gravity of the helmet. The resulting helmet design would of itself increase protection and stability over the standard M-1.

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Natick personnel designed the helmet in a step-wise fashion, addressing each of the program generated design parameters. Using the "working helmet molds" which possessed the stand-off and edge-cut demarkation lines, clay models were worked and re-worked until all the design parameters blended into an esthetic military entity having strong military lines. The final design was cast molded in hydrostone (3 sizes) and the cast models used in suspension system studies.

6. SUSPENSION SYSTEMS

To maintain a minimum 1/2 inch helmet stand-off on all heads required the development of a new suspension system.

A suspension system is defined as that component of a helmet which comes in contact with the head; it supports and secures the helmet on the head. When a chinstrap is used, it is considered a part of the suspension system.

Suspension systems are generally of three basic designs: cradle type, padded type, or combinations thereof. A cradle suspension consists of a circumferential band affixed to the helmet usually at 4 to 6 points and an over-the-head portion that suspends the helmet a given distance from the head. A cradle suspension usually provides for circumferential and height adjustments. Padded suspension systems usually consist of expanded elastomers (foams) filling all or part of the void between the head and the helmet. If adjustment is provided, it is often by means of the addition or elimination of fitting pads.

NARADCOM's experience on suspension systems over the years show that a cradle type suspension is the most practical for use in an infantry helmet. This conclusion has been verified many times by industrial experts. Ventilation design parameters are best met by the cradle type suspension developed for the new helmet. The new suspension incorporated many of the desirable features of past suspension work. Those characteristics that would yield greater comfort, stability, compatibility and safety were designed into the suspension.

The suspension system developed for the helmet is a replaceable cradle type in three sizes that is attached to the helmet with screws and threaded A-washers. The construction is primarily nylon with a self-compensating drawstring adjustment at the top. The drawstring uses a velcro tab for rapid height adjustment and the suspension is dimensioned to preclude contact of the

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helmet with the head under all conditions. The headband utilizes velcro pile to prevent the head clips from coming in contact with the head. The headband clips are of a new design with a positive lock to preclude release under impact. The leather covering of the headband is not sewn at the top and overlaps the top of the headband itself. The chinstrap, a two-point open chin cup, utilizes pivots at the attachment points in order to provide better comfort and incorporates a new style buckle for easier adjustment. In general, the suspension system is designed to provide increased stability by having a high tension in the circumferential straps and uniform tension in the over-the-head straps; increased safety by minimizing the amount of interior hardware; and increased comfort by a combination of features of the headband and chinstrap.

7. FABRICATION OF MOCK-UP HELMETS

The scheduled HEL human factors evaluation of the new helmet design required this Command to fabricate 36 prototype helmets faithful to the design, weight and esthetic qualities of the selected model. Time and cost did not permit the building of matched metal compression molds so a unique fabrication technique was conceived. Since laminated Kevlar was the most promising ballistic material, the thickness and weight of the helmet made from this material was calculated for a 38 oz/ft² areal density (the areal density of the M-1). The sculptor made male vacuum forming molds for each size helmet conforming to the inside surfaces of the helmets; and female molds which represented the outside surfaces of the helmets (actually the male mold plus .350 inches thickness). ABS molded shells were obtained from each respective mold. The male shell was placed into the female shell separated by spacers. The volume of the resulting space was determined by filling with water. Knowing the weight of the inside and outside shells and the volume in between, the exact weight of the corresponding Kevlar helmet was obtained by filling the space with an epoxy resin having the proper specific gravity. Eighteen helmets, six in each size, were made at this weight. The MN (Materiel Need) requirements permitted a lighter helmet with protection equivalent to the M-1, so eighteen helmets were made using a resin of lower specific gravity which resulted in helmets weighing approximately 12 to 14 ounces less than the epoxy filled mock-ups. These were equivalent to 30 oz/ft² areal density Kevlar helmets. All helmets were painted with a camouflage pattern.

The nylon, six point cradle suspension system described in the previous section was fabricated and inserted into the helmets.

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The helmets were delivered to the Human Engineering Laboratories, Aberdeen, MD in April 1974 for human factors field evaluation of the ground troop personnel armor system which included both weights of helmets and two new armored vests.

8. HUMAN FACTORS EVALUATION OF HELMETS AND BODY ARMOR

A detailed discussion of the techniques and procedures used in the HEL evaluations is contained in (15). The conclusions of that study are quoted here:

"Systems I (equivalent protection) and II (increased protection) - These two helmet vest systems can be considered a successful solution, ergonomically, for use by the infantryman. Improvements gained from sizing systems, for both helmet and vest, helmet balance, area coverage, body system interaction, compatibility with selected infantry employed weapons, equipment systems, mobility and soldier acceptance far outweigh the limited number of negative findings.

System III (Standard M-1 and Vest) - This system cannot be considered an acceptable solution, ergonomically, for use by the infantryman. The many problems occurred with this system - the lack of sizing for the helmet, outdated sizing for the vest, helmet instability, poor area coverage, and negative body-system interactions - result in an overall poor rating by the subjects."

9. LARGE SCALE FITTING TEST

The small fitting test run during the HEL human factors evaluation did not reveal any problems. However, before investing money and time in obtaining finished helmets, a large scale verification fit test was conducted at Fort Devens, MA in July 1974(16). Over 400 subjects from the 10th Special Forces were measured and fitted with the new helmet. In addition, the minimum designed 1/2 inch stand-off was verified on all heads. The stand-off verification was accomplished by probing through the helmet at 13 selected locations. The tariff of the new helmet system proved to be 20% small, 50% medium and 30% large.

10. CONCLUSIONS

With the final set of master models verified, the helmet design program was complete. Matched metal molds were procured and helmets were successfully manufactured for DTII/OTII testing (Fig. 3), scheduled in September 1976.

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The objectives of the helmet program were met. The philosophy and plans of the helmet program were followed in detail and every feature of the helmet design was documented. The new helmet design in three sizes fit the 1st to the 99th percentile of the US Army population. The helmet is comfortable and stable, covers more of the head, and provides more ballistic protection than the M-1 steel shell and nylon liner.

Generalized shaped headforms representing the US Army population were developed. Scientific techniques were used to establish baseline helmet data, and evaluation and measuring techniques were established which can be used in the development of any future helmet.

Fig. 3. A compression molded Kevlar Infantry Helmet

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Figure 3

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